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**Integrated Circuitry and Semiconductor Processing
Method of Forming Field Effect Transistors**

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INVENTORS

Jigish D. Trivedi
Zhongze Wang
Rongsheng Yang

ATTORNEY'S DOCKET NO. MI22-1194

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TECHNICAL FIELD

3 This invention relates to methods of forming field effect transistors,
4 and to field effect transistors and to integrated circuitry.

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BACKGROUND OF THE INVENTION

6 Field effect transistors (FET's) are routinely included in integrated
7 circuitry with a metal-oxide-silicon (MOS) structure. The MOSFET
8 design comprises a pair of diffusion regions, one referred to as a source
9 and the other a drain, each spaced apart within a semiconductive
10 material. This design includes a gate provided adjacent to a separation
11 region between the diffusion regions for imparting an electric field to
12 enable current to flow between the diffusion regions. The substrate
13 separation region adjacent the gate and between the diffusion regions is
14 referred to as a channel. The semiconductive substrate typically
15 comprises silicon having a light conductivity dopant concentration.

16 To aid in interpretation of the claims that follow, the terms
17 "semiconductive substrate" and "semiconductor substrate" are defined to
18 mean any construction comprising semiconductive material, including, but
19 not limited to, bulk semiconductive materials such as a semiconductive
20 wafer (either alone or in assemblies comprising other materials thereon),
21 and semiconductive material layers (either alone or in assemblies
22 comprising other materials). The term "substrate" refers to any
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1 supporting structure, including, but not limited to, the semiconductive
2 substrates described above.

3 A MOSFET structure is typically fabricated during semiconductor
4 processing by superimposing several layers of conducting, insulating and
5 transistor forming materials. After a series of processing steps, a typical
6 structure might comprise levels of diffusion, polysilicon and metal that
7 are separated by insulating layers. There are generally two types of
8 MOSFETs, namely an n-type transistor and a p-type transistor. These
9 transistors are fabricated within the semiconductor substrate by using
10 either n-type doped silicon that is rich in electrons or p-type doped
11 silicon that is rich in holes. Different dopant ions are utilized for
12 doping the desired substrate regions with the desired concentration of
13 holes or electrons.

14 The semiconductor industry continually strives to decrease the
15 device size of components in an integrated circuit thereby increasing the
16 overall performance speed. Accordingly, p-type and n-type field effect
17 transistors are routinely included in integrated circuitry fabrication
18 adjacent one another in ever closer proximities. However, as the spacing
19 between the n-type and p-type field effect transistors on a substrate
20 decreased, undesired effects developed. A challenge in fabrication of
21 both transistors is to synchronize the fabrication of the paired p-type and
22 n-type devices so that desired performance is achieved. As a result,
23 device design, and consequently process technology, had to be modified

1 to take these effects into account so that optimum device performance
2 could continue to be obtained.

3 The gates for each transistor type are routinely fabricated from the
4 same polysilicon layer heavily doped with an n-type material. Such
5 designs for p-type MOSFETs can include a p-type doped region formed
6 within the channel region between the source/drain. However, as gate
7 widths decrease to below 0.3 microns, this design can allow significant
8 current leakage and increase the difficulty of designing MOSFETs with
9 low threshold voltages to function with low power supplies. A solution
10 is to heavily dope the p-transistor gates with p-type dopant instead of
11 n-type dopant. However, this solution has its own problem. The p-type
12 dopant can diffuse from the gate into the channel to cause significant
13 current leakage between the source/drain regions.

SUMMARY OF THE INVENTION

In accordance with an aspect of the invention, a semiconductor processing method of forming field effect transistors includes forming a first gate dielectric layer over first and second areas of a semiconductor substrate. The first area is configured for forming p-type field effect transistors and the second area is configured for forming n-type field effect transistors. The first gate dielectric layer includes silicon dioxide having nitrogen atoms concentrated therein, the nitrogen atoms being higher in concentration within the first gate dielectric layer at one elevational location as compared to another elevational location. The nitrogen concentration at the one elevational location preferably ranges from 0.1% molar to 10.0% molar. The first gate dielectric layer is removed from over the second area while leaving the first gate dielectric layer over the first area. After removing the first gate dielectric, a second gate dielectric layer is formed over the second area. The second gate dielectric layer includes silicon dioxide proximate an interface of the second gate dielectric layer with the semiconductor substrate and the second gate dielectric layer is substantially void of nitrogen atoms. Next, transistor gates are formed over the first and second gate dielectric layers, and then p-type source/drain regions are formed proximate the transistor gates in the first area and n-type source/drain regions are formed proximate the transistor gates in the second area.

1 In another aspect of the invention, integrated circuitry includes a
2 semiconductor substrate having an area within which a plurality of n-type
3 and p-type field effect transistors are formed. The respective transistors
4 include a gate, a first gate dielectric layer for the p-type transistors and
5 a second gate dielectric layer for the n-type transistors, and source/drain
6 regions. The first gate dielectric layer includes silicon dioxide having
7 nitrogen atoms therein. The nitrogen atoms are higher in concentration
8 within the first gate dielectric layer at one elevational location as
9 compared to another elevational location. The nitrogen concentration
10 preferably ranges from 0.1% molar to 10.0% molar. The second gate
11 dielectric layer includes silicon dioxide material proximate an interface of
12 the second gate dielectric layer with the semiconductor substrate which
13 is substantially void of nitrogen atoms.

14 In another aspect of the invention, a semiconductor processing
15 method of forming field effect transistors includes providing a continuous
16 area over a semiconductor substrate for formation of n-type and p-type
17 field effect transistors. The transistors include a gate, a gate dielectric
18 layer and source/drain regions. A predominate portion of the gate
19 dielectric layers of the p-type transistors are formed in the continuous
20 area prior to forming a predominate portion of the gate dielectric layers
21 of the n-type transistors in the continuous area.
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BRIEF DESCRIPTION OF THE DRAWINGS

Preferred embodiments of the invention are described below with reference to the following accompanying drawings.

Figure 1 is a fragmentary sectional view of a semiconductor substrate at one processing step in accordance with one embodiment of the invention.

Figure 2 is a view of the Figure 1 substrate fragment at a processing step subsequent to that shown in Figure 1.

Figure 3 is a view of the Figure 1 substrate fragment at a processing step subsequent to that shown in Figure 2.

Figure 4 is a view of the Figure 1 substrate fragment at a processing step subsequent to that shown in Figure 3.

Figure 5 is a view of the Figure 1 substrate fragment at a processing step subsequent to that shown in Figure 4.

Figure 6 is a view of the Figure 1 substrate fragment at a processing step subsequent to that shown in Figure 5.

Figure 7 is a view of the Figure 1 substrate fragment at a processing step subsequent to that shown in Figure 6.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

This disclosure of the invention is submitted in furtherance of the constitutional purposes of the U.S. Patent Laws "to promote the Progress of Science and useful Arts" (Article 1, Section 8).

With reference to Figures 1-7, an embodiment of the method of the present invention is illustrated. The present invention encompasses a method of forming p-type and n-type field effect transistors on a substrate, particularly a semiconductor substrate. The semiconductor substrate includes a first area of one conductivity type region and a second area of another conductivity type region. As illustrated, the first area is a p-type region and the second area is a n-type region. While the shown embodiment has the p-type transistor in a first area, it is to be understood and described subsequently that the areas of n-type and p-type transistors shown in Figures 1-7 can be reversed.

Referring to Figure 1, a semiconductor substrate fragment in process is indicated generally by reference numeral 10. A first area 12 is configured for p-type transistor fabrication and a second area 14 is configured for n-type transistor fabrication. First and second areas 12/14 may be referred to as regions, or p-type or n-type areas, or any combination thereof. Although first area 12 and second area 14 are shown as separate areas, it should be understood that the two areas can be continuous over semiconductor substrate 10. P-type region 12 includes bulk substrate material 18, preferably composed of

monocrystalline silicon, and trench isolation regions 22. N-type region 14 comprises bulk substrate material 16, preferably composed of monocrystalline silicon, and trench isolation regions 20.

Referring to Figure 2, a first gate dielectric layer 28 is formed over the p-type and n-type areas 12/14 of the semiconductor substrate 10. Such is preferably formed by a sequence of dry and wet oxidation steps. In a first step, semiconductor substrate 10 is provided in a batch six liter reactor (not shown) at 775°C, atmospheric pressure, for approximately four minutes. Oxygen is fed to the reactor at 6,000 sccm, N₂ at 50 sccm and a chlorine source gas at 50 sccm (i.e., trichloroethylene, trichloroethane, dichloroethylene, and anhydrous hydrogen chloride, as examples only). This preferably forms a 10 to 20 angstroms thick layer of first gate dielectric layer 28 on the semiconductor substrate 10.

Subsequently, wet processing is preferably conducted at 775°C, atmospheric pressure, for approximately 9 minutes. Oxygen is fed to the reactor at 6,000 sccm, H₂ at 3,000 sccm, N₂ at 50 sccm and a chlorine source gas at 50 sccm. The result is preferably growth of an additional 40 angstroms of layer 28. Subsequently, another "dry" processing is preferably conducted, for example, at 775°C, atmospheric pressure, for approximately 5 minutes. Example gas flows are O₂ at 6,000 sccm and pure N₂ at 1,000 sccm. The result is 10 angstroms of additional first gate dielectric layer 28. Accordingly and preferably, first

1 gate dielectric layer 28 has been fabricated to comprise an oxide, such
2 as silicon dioxide.

3 Referring to Figure 3, an interface 31 is indicated where first gate
4 dielectric layer 28 meets substrate material 16/18. First gate dielectric
5 layer 28 is formed to have nitrogen atoms therein, the nitrogen atoms
6 being higher in concentration within the first dielectric layer at one
7 elevational location as compared to another elevational location. The
8 nitrogen concentration could peak at any elevational location, preferably
9 in a region 30 at a location proximate interface 31. Further preferably,
10 the nitrogen atoms are provided to have a concentration of from 0.1%
11 molar to 10.0% molar within region 30, and more preferably from 0.5%
12 to 5.0% molar. An exemplary thickness for region 30 is from 30 to 60
13 angstroms. Processing to produce the Figure 3 construction could be
14 conducted in a number of different manners. For example, the
15 semiconductor substrate 10 can be provided in a furnace (not shown) for
16 thermal processing. An example processing is at a temperature ranging
17 from 750°C to 950°C, ideally 850°C, and at atmospheric pressure. A
18 nitrogen source 50 is provided at about 100 to 10,000 sccm, ideally 1,000
19 sccm, for a period of from 5 minutes to 2 hours, ideally 30 minutes.
20 The preferred sources of nitrogen have an N-O bond because of the
21 ease of breaking the nitrogen bonds. However, other sources can be
22 used. Examples include, in descending order of preference: NO, N₂O,
23 NH₃, and N₂.

1 Rapid thermal processing (RTP) is another method to provide
2 nitrogen atoms within gate dielectric layer 28. The method preferably
3 includes providing one of the four previously listed nitrogen based
4 compounds in a reactor. The reactor is heated to a range of from
5 about 800° to 1200°C at atmospheric pressure with the temperature
6 increasing at a rate from about 10°C per second to 200°C per second
7 peaking at a time range of 10 seconds to 2 minutes. Additional
8 example alternatives to provide nitrogen atoms within gate dielectric
9 layer 28 include nitrogen plasma treatment and nitrogen ion implant.

10 A preferred goal in such processing is to produce Si-N bonds at
11 least partially along interface 31 in region 30. A preferred purpose for
12 such region 30 is to prevent subsequent out diffusion of p-type material
13 from a transistor gate layer into a transistor channel. Another preferred
14 goal by provision of such nitrogen atoms is subsequent restriction of
15 further oxidation of layer 28 as semiconductor substrate 10 is further
16 processed, as will be described. An optional further thermal processing
17 of semiconductor substrate 10 may be performed after forming nitrogen
18 region 30 to re-oxidize first gate dielectric layer 28. An example re-
19 oxidation process is at 900°C in pure N₂ at 1,000 sccm, O₂ at 6,000
20 sccm, N₂ at 50 sccm and a chlorine source gas at 50 sccm for a period
21 of 50 minutes.

22 Referring to Figure 4, first gate dielectric layer 28 is removed
23 from over one of the first and second areas and left over the other of

1 the first and second areas. In the depicted and preferred example, first
2 gate dielectric layer 28 is removed from over second area 14 and left
3 over first area 12. Alternately, but less preferred, this could be
4 reversed. An example process for achieving such removal comprises
5 depositing and processing photoresist over semiconductor substrate 10 to
6 mask p-type region 12 and leave n-type region 14 exposed. An etching
7 process is then preferably performed to strip the first gate dielectric
8 layer 28 from the n-type region 14. The photoresist is then removed
9 and the semiconductor substrate 10 is preferably cleaned with a water,
10 H_2O_2 , and HF mix. Before removal of the photoresist, an optional
11 channel enhancement implant can be performed in the substrate
12 material 16 of n-type region 14 before or after stripping the first gate
13 dielectric layer 28.

14 Referring to Figure 5, a second gate dielectric layer 32 is primarily
15 formed over the other of the first and second areas 12/14. Preferably,
16 a second gate dielectric layer 32 is formed in the same manner as
17 previously described above for first gate dielectric layer 28 (excluding the
18 process forming the nitrogen region 30). Accordingly, second gate
19 dielectric layer 32 is preferably formed to comprise an oxide, such as
20 silicon dioxide, proximate interface 31 of second gate dielectric layer 32
21 with semiconductor substrate material 16. Alternative methods to form
22 second gate dielectric layer 32 include performing one or any
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1 combination of the previously described "dry" and "wet" methods for
2 forming first dielectric layer 28.

3 As illustrated, the process to form second gate dielectric layer 32
4 preferably provides the primary layer for second gate dielectric over the
5 n-type region 14. The thickness of second gate dielectric layer 32 can
6 be selected or optimized for the second area 14 transistors by varying
7 process conditions, such as temperature, pressure and processing time.
8 Additionally, as indicated, the process can result in an additional layer
9 over first gate dielectric layer 28, preferably less than 5 angstroms.
10 Accordingly, first area 12 transistors and second area 14 transistors can
11 have their gate dielectric properties separately and selectively optimized.
12 Further, most preferably, second gate dielectric layer 32 is fabricated to
13 be substantially void of nitrogen atoms unlike the fabrication of first gate
14 dielectric layer 28 proximate interface 31. In the context of this
15 document, "substantially void of nitrogen atoms" means any nitrogen
16 atom concentration less than or equal to 0.1% molar.

17 Accordingly in the preferred embodiment, first gate dielectric
18 layer 28 is different in composition relative to second gate dielectric
19 layer 32, at least relative to nitrogen atom presence most proximate
20 interface 31. Further, the first and second gate dielectric layers may,
21 or may not, be different thicknesses relative to one another, depending
22 on the chosen performance characteristics for the transistors. Further,
23 first gate dielectric layer 28 has been formed before second gate

1 dielectric layer 32, although such could be reversed. Further, second
2 gate dielectric layer 32 is preferably formed to at least initially cover all
3 of first and second areas 12/14. An alternative method of forming
4 second gate dielectric layer 32 could be to at least initially cover only
5 second area 14, or only a majority of second area 14.

6 Preferably as shown, at least a predominate portion of the gate
7 dielectric layers of the p-type transistors are formed prior to forming a
8 predominate portion of the gate dielectric layers for the n-type
9 transistors. Further, the p-type transistor gate dielectric layer preferably
10 has nitrogen atoms therein to serve as a diffusion barrier to out
11 diffusion of p-type material from the gate into the channel region.
12 Further, such nitrogen also preferably will function to restrict further
13 oxide growth of layer 28 while layer 32 is being formed. The capability
14 of selectively designing varying gate oxide thickness and gate oxide
15 quality is ideal for semiconductor structures including, but not exclusive,
16 high performance SRAM/LOGIC/Embedded DRAMs, and DRAM designs
17 utilizing surface p-type devices.

18 Referring to Figure 6, a gate layer 34 is provided over p-type
19 region 12, and a gate layer 36 is provided over n-type region 14, ideally
20 polysilicon for both. Preferably, gate layer 34 over the p-type region 12
21 is doped with a p-type material, preferably boron, while gate
22 layer 36 over the n-type region 14 is doped with a n-type material.
23 Alternatively but less preferred, layers 34 and 36 might comprise the

1 same conductivity type dopant. A layer 38 comprising one or any
2 combination of elemental metals, metal alloys, metal silicides and metal
3 nitrides is formed over layers 34 and 36. An insulative layer 39 is
4 formed over layer 38. An exemplary layer 39 comprises silicon dioxide
5 deposited by a TEOS source.

6 Referring to Figure 7, another sequence of applying photoresist,
7 masking, and etching is preferably performed to the layers and
8 semiconductor substrate to form gate structure 40 over the p-type
9 region 12 and gate structure 42 over the n-type region 14. Insulative
10 spacers 44 can be formed adjacent gate structures 40 and 42. P-type
11 source/drain regions 26 are formed proximate the transistor gate 40 in
12 the first area 12 and n-type source/drain regions 24 are formed
13 proximate the transistor gate 42 in the second area 14. If desired, a
14 silicide layer (not shown) can be formed over n-type and p-type
15 source/drain regions 24/26.

16 Such constitutes but one example of forming a p-type transistor
17 over p-type region 12 and an n-type transistor over n-type region 14.
18 Preferably as described, only the p-type transistor includes the nitrogen
19 concentration region 30 to act as a barrier to the boron in the heavily
20 doped polysilicon gate.

21 The invention also contemplates integrated circuitry fabricated by
22 the above and other processes.
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1 In compliance with the statute, the invention has been described
2 in language more or less specific as to structural and methodical
3 features. It is to be understood, however, that the invention is not
4 limited to the specific features shown and described, since the means
5 herein disclosed comprise preferred forms of putting the invention into
6 effect. The invention is, therefore, claimed in any of its forms or
7 modifications within the proper scope of the appended claims
8 appropriately interpreted in accordance with the doctrine of equivalents.
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